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A Seismic Data Analysis Console

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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LINCOLN LABORATORY

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Group 22

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ABSTRACT

A software system has been developed to manipulate, process, and display digital data. This system emphasizes man-machine interaction by featuring input-output convenience, quick visual inspection of the data, and easy application of a library of processing programs. Additional programs can be added easily to the system's library. Although the facilities described herein were developed for seismology, they can be used equally well to analyze any type of digitized data.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

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A SEISMIC DATA ANALYSIS CONSOLE

I. INTRODUCTION

Several large arrays of seismometers have recently been built to record signals from seismic events. These signals are used to discriminate between underground explosions and earthquakes – a necessity for policing a nuclear test ban treaty. The output of these arrays is recorded on digital tapes, a medium which is superior to analog tapes, film, or chart recordings in terms of multichannel capability, precise timing, greater dynamic range, and digital-computer compatibility. However, experimenters are reluctant to use digital systems, both because of the increased cost and complexity concomitant with these systems and also because digital data are difficult to examine visually. This report describes a Data Analysis Console† designed expressly to facilitate the inspection and processing of the large amounts of digital data produced by the seismic arrays.‡ Seismologists who use this Console now find dealing with digital data both convenient and enjoyable. Although it was originally developed for seismic waveforms, this system can also be used to analyze properly formatted§ digital data from other sources. In addition to seismic data, the Console has been used to analyze data from pollution studies and from the Apollo moon program. Some of those data were originally in analog form and were digitized by our computer.

II. GENERAL DESCRIPTION

The Data Analysis Console is a system of computer programs with graphical output designed to operate in concert on multichannel digital data.¶ The system interfaces a man to the computer by quickly displaying the input data or the processing results in an easily interpretable manner. The man, in turn, can adjust the data or give new commands to the computer via a fiber optics light pen, control knobs, or a teletypewriter keyboard (see Fig. 1). This man-machine system has a human analyst performing pattern recognition and decision making based on his judgment as an experienced seismologist or scientist. He performs only those tasks which are very difficult for a modern electronic computer to effect; the computer does only those tasks which it can execute faster or more efficiently than a man.

The Console is designed to perform many of the standard data-processing tasks efficiently and accurately, and yet be faster and easier to use than a "batch processing" computer of the type found in most modern data centers. One difficulty inherent in processing geophysical data in the conventional manner arises from the large amounts of input data required and output data produced. For example, the input might typically be a reel of magnetic tape, while the output might be 25 feet of 32-channel chart recording, of which only 25 constants are useful; these may be the input, along with the original data tape, to the next step in the processing. Each pass

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† An earlier version of this system, using different hardware, is described in Ref. 1.

‡ At Lincoln Laboratory, we have a library of over 10,000 digital magnetic tapes of seismic events selected from the more than 1000 tapes recorded each month by these arrays. Appendix C describes the contents of this data library.

§ One of our most versatile input tape formats is described in detail in Appendix B.

¶ Appendix A is a list of the basic Console programs.

Fig. 1. Photograph of operator at Data Analysis Console.

through the computing center takes time, generates superfluous data, and can introduce human error in setting up the next run (e.g., errors in reading the chart recorder and transcribing to punched cards).

The Console was designed to eliminate these difficulties by incorporating the following features:

(a) The operator can conveniently extract from large amounts of data only those data which he desires to see.

(b) These data are presented in a quasi-analog manner, that is, they appear analog to the eye and can be manipulated by analog devices, such as knobs and a light pen, yet the full accuracy of the digital values is retained for further computation because the data never leave the computer.

(c) All the salient parameters of each program are saved in a common area of the computer memory.

(d) The operator has a powerful library of general analysis programs available at his fingertips.

(e) Only after the data have been reduced, or after the operator decides that he really wants them, is permanent output produced in the form of teletype copy, punched paper tape, or full-scale hard copies of the scope display.

As an example, suppose an analyst wishes to find the frequency spectrum of a certain class of events. He uses the Console display program to view the input data tape to insure that it is indeed the data he desires to process. If he should find a glitch, he calls a deglitching program to fix it. He selects a portion of the data he finds interesting by pointing a light pen at it and calls another program to take and display its spectrum. Finally, if he decides it is relevant, he gets a hard copy of the spectrum.

This ability to process the results of a prior processing without punching data cards and submitting for another pass through the computer center saves time. Typically, operations that take several days using batch processing can be done in a few minutes on the Data Analysis Console.

New programs can be added easily to the Console library when the need arises. Because of the modular organization system, a new program can take advantage of the existing programs to read in, display, and organize data. By using the common data storage and the waveform data stored on the drum, the results of existing Console programs can be the input to a new program, and the output from a new program may be used as input to current Console programs. Scientists with only a basic knowledge of Fortran can add their own specialized processing programs with a minimum of effort.

The operation and control of the Console are done by a master software monitor, which always resides in the computer core memory. This monitor controls the calling and execution of all the Console programs which are stored on the drum in a program file. Only the monitor program must be manually read in to the computer; this is done once at the start. All commands to the monitor are input to the computer from the teletypewriter keyboard as a three-character mnemonic code prefixed by the special character >. The monitor will fetch the requested program from the program library, transfer it into core memory, and execute it. All the programs automatically return to the monitor carrying the name of the program the monitor should call next. The monitor is also used to add and delete programs from the program library.

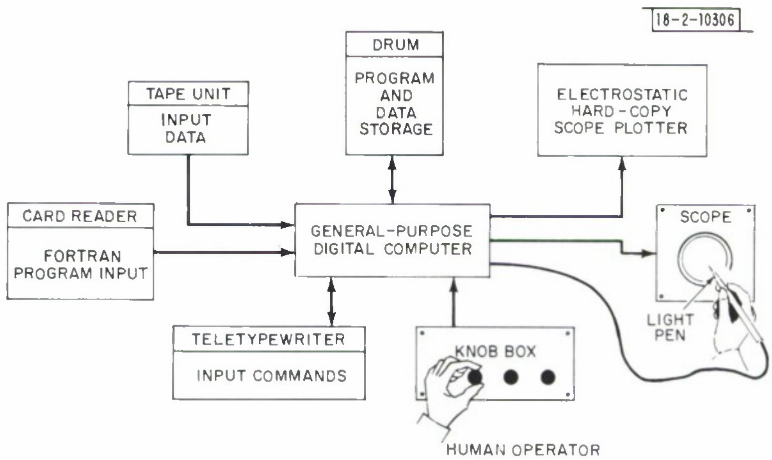


Fig. 2. Block diogrom of Data Analysis Console.

Our particular hardware configuration (Fig. 2) consists of two identical PDP-7s, each with 32,768 eighteen-bit words of core memory, extended arithmetic element, automatic priority interrupt, teletypewriter, display scope, and three 7-track IBM-compatible tape drives. They share an electrostatic printer and a 3,145,728-word drum which contains the program library and the digital data being processed. Each computer has a card reader that is used to input Fortran programs for compilation. Two knob boxes are the only home-built devices attached to the computers. Each box consists of one 64-turn digital shaft encoder and 12 helipots which are connected to a precision voltage source to provide 12 independently adjustable voltages. The shaft encoder is directly connected to the computer's information collector, while the 12 voltage divider outputs are connected to a computer-controlled multiplexer analog-to-digital converter. The software system described in this report is self-contained in each PDP-7, that is, we have two Data Analysis Consoles which can be run simultaneously on different data.

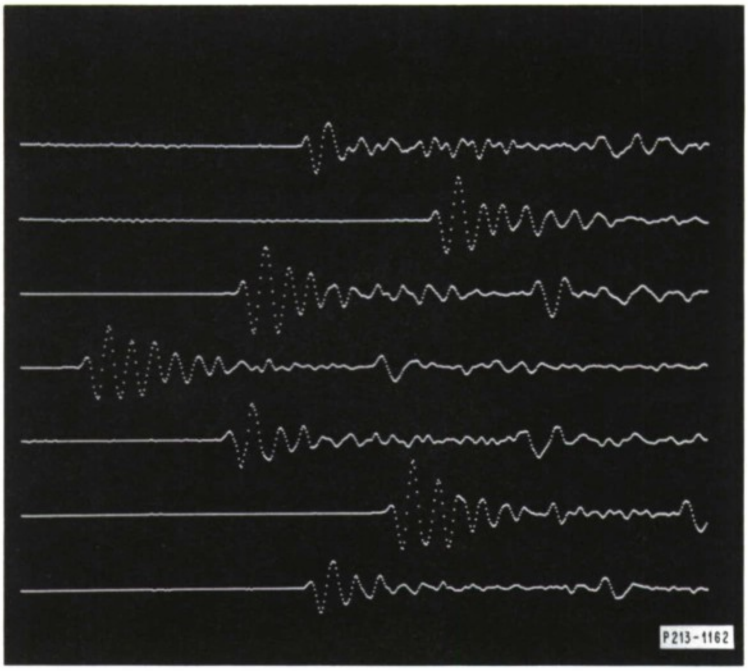


Fig. 3(a). Seismagrams fram earthquake in Andreanoff Islands as recarded at LASA in Mantana. Character and arrival times af seismic waves are different because seismameters are separated by up ta 180 km. This is minimum horizontal gain setting; harizontal scale cavers 21.6 sec.

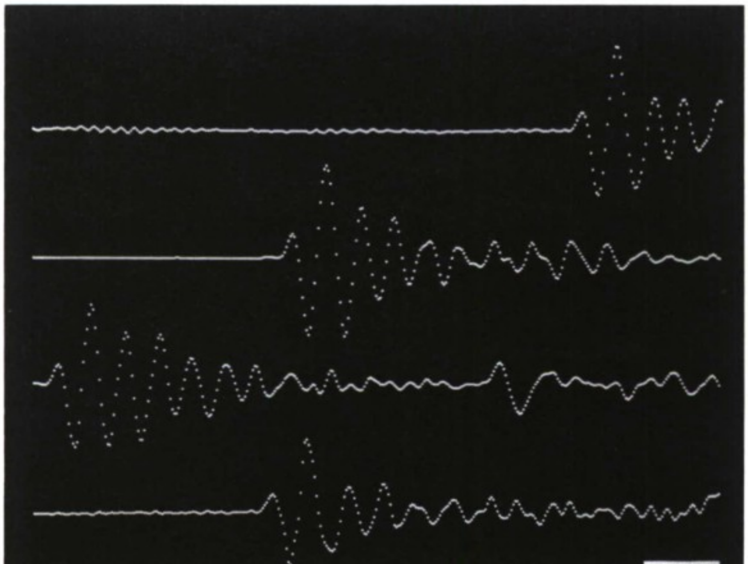


Fig. 3(b). Channels 2 thraugh 5 with mare gain (harizontal range is 17 sec).

III. DATA ANALYSIS CONSOLE PROGRAMS

A. Initialize (>INT)†

The first program called reads the magnetic tapes, selects data that the operator chooses, and stores salient parameters describing the selected data in a common area of the computer memory. All other Console programs have access to the information in the common area.

Some of these parameters are determined by codes in the tape format; others are chosen by the operator or calculated from his choices. These parameters include the sampling interval, the number of channels, the latitude and longitude of the seismometer corresponding to each channel, the total number of samples per channel, the starting Greenwich Mean Time (GMT) of each channel, and the instrument gain in millimicrons/data level.

The operator may select up to a maximum of 32 channels. Those selected may be a subset of many channels multiplexed onto any file of one input tape, or they may be gathered (one or more at a time) from separate data tapes. In order to save typing 32 numbers, the operator may choose one of several standard sets of channels which are defined for each tape format by typing only one letter. The data from any channel may be on any file of the input tape, or it may be recorded consecutively on two or more tapes.

The operator may choose a short data buffer (3840 samples for each channel) or a long data buffer (384,000 samples divided evenly among the channels designated). The computer types the date, starting time, and format of each input tape; the operator selects both the time of interest and the decimation to be used (i.e., only accept every n^{th} data sample). The computer puts the proper data into the drum memory so that the requested time for each channel is one-quarter of the way into the data buffer. When all the data have been read in, the display program will show the desired data starting at the requested time.

B. Display (>DIS)

This program is the heart of the Data Analysis Console. Any Console program may be called at any time from the display program by typing the proper code letters; most programs return here when they are through.

This program displays the waveform data (amplitude vs time) on the scope; five knobs set the parameters of the display. The knobs control the horizontal and vertical gain, the horizontal and vertical position, and the vertical separation between the waveforms. The waveforms can be imagined as stored in an internal scroll. Thus, as the vertical position knob is turned, old traces move off the screen at the top or bottom and new ones appear at the other end. The range of the horizontal position knob allows all the data stored in the buffer to be displayed. Because the buffer can be so large (up to 384,000 data samples) the 64-turn shaft encoder is used for this function. All the other knob parameters are set by the 10-turn helipots. Horizontal gain can be adjusted so that from 5 to 512 samples of each waveform cover the 10-inch display screen. The range of the vertical gain knob covers plus-to-minus 0.07 mm/data level (including zero), so that the data can be inverted. Vertical separation can be adjusted to show from 1 to 32 waveforms, but the total number of points displayed can never exceed 4000. Figures 3(a) through (c) show some examples for various settings of these knobs.

If any one of the displayed waveforms is "touched" by the light pen, the following things will occur (see Fig. 4). First, a copy of the selected waveform will appear at the top of the screen,

† The 4 characters in parentheses following each program name are the actual code characters that the operator types to execute the program.

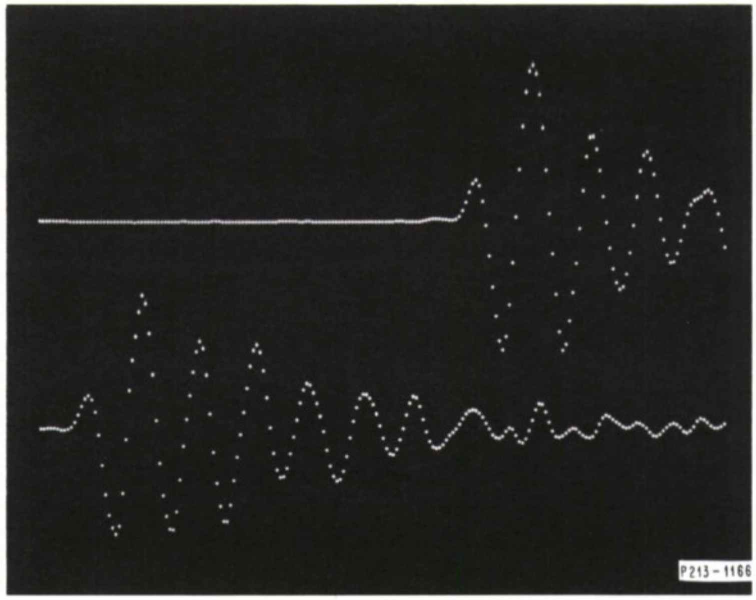


Fig. 3(c). Channels 3 ond 4 with even more goin (horizontal ronge is 10 sec).

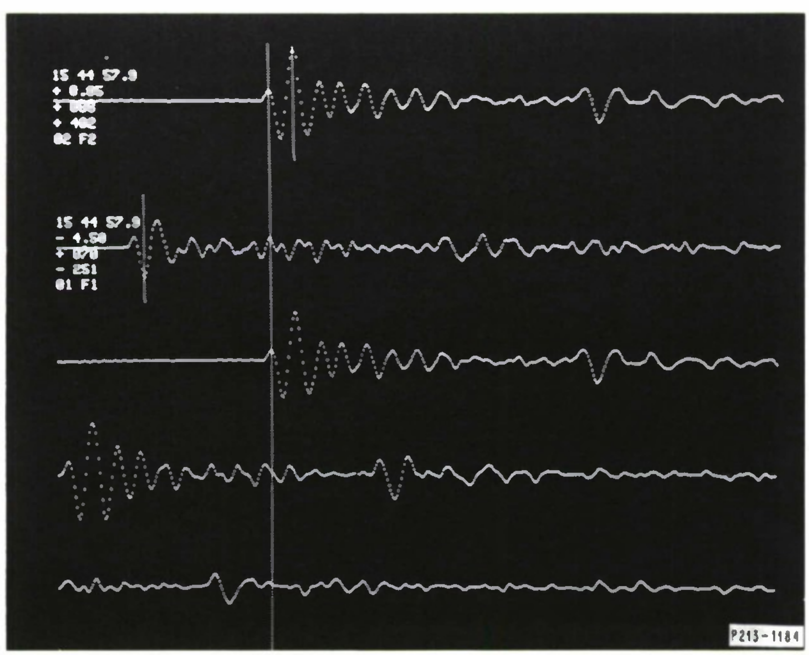


Fig. 4. Second chonnel hos been chosen as reference and appears at top of screen. Top set of numbers show that time at long cursor is 15h 44m 57.9s; reference short cursor is 0.85 sec from long cursor; reference amplitude is 88 mμ at long cursor and 402 mμ at short cursor; and reference channel is chonnel 2 which contains doto from LASA site F2. Second set of numbers shows same parameters for top data trace (second trace shown). These numbers will chonge continuously as display is changed by knobs.

and 3840 samples will be saved in the drum memory where they will be available as input to other processing programs. This reference trace displayed at the top of the screen will be fixed in place; it will be unaffected by the horizontal position knob. Second, a long vertical cursor will appear on the screen at the exact point that was touched by the light pen. Two other short cursors will appear: one on the reference trace, and one on the top data trace. The position of each short cursor is set by a control knob. The position of all three cursors will be saved in the common area of the computer memory. Finally, two sets of numbers will appear on the left side of the screen; one is associated with the reference trace, and one is associated with whichever data trace appears just below the reference. The numbers in each set will represent the current values of the following variables: the absolute time at the point where the large cursor crosses the trace, the time difference from the large cursor to the small cursor, the amplitude at the point where each cursor intersects the trace, and a channel identifier. The reference trace may be filed in any data channel or added following the last data channel used (up to channel 32). A new reference may be selected at any time; it will displace the old reference, which will then be lost unless it has been filed.

Time picking is the process of lining up each waveform one by one with the reference in order to determine the arrival times at the various sites [see Figs. 5(a) and (b)]. These times are stored in the common area and may be used by the other Console programs for beamforming and locating the event source (as described later). All channels can be aligned according to their time picks (Fig. 6).

The display program also saves several other parameters in the common area for use by other programs. These parameters include the sample number of each of the cursors, the time and amplitude difference between the two reference cursors, the sample number of the start of the display, the number of the channel at the top of the screen, the sample number of the time pick made for each channel, and the channel number, instrument gain, and starting time and sample number of the reference.

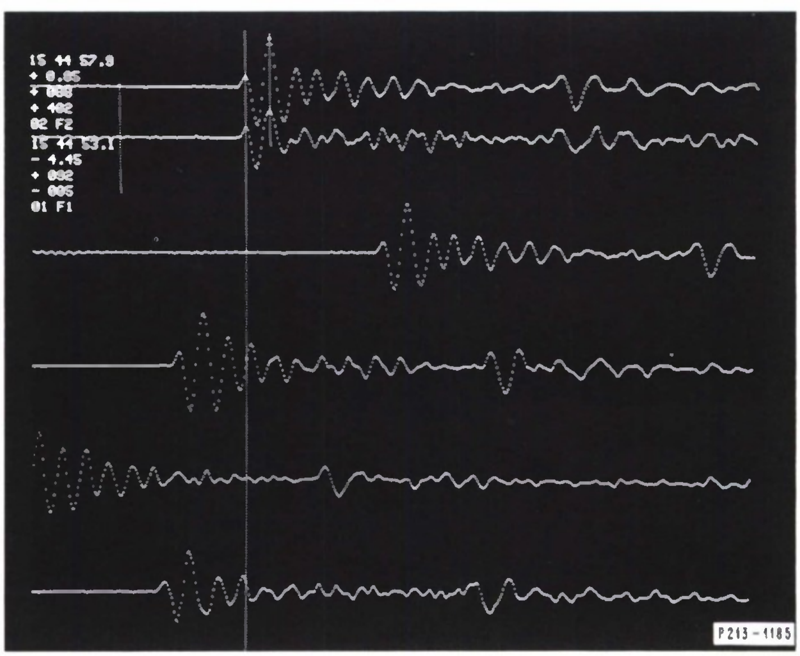


Fig. 5(a). Time picking — first maximum of site F1 has been aligned with reference (site F2) by operator.

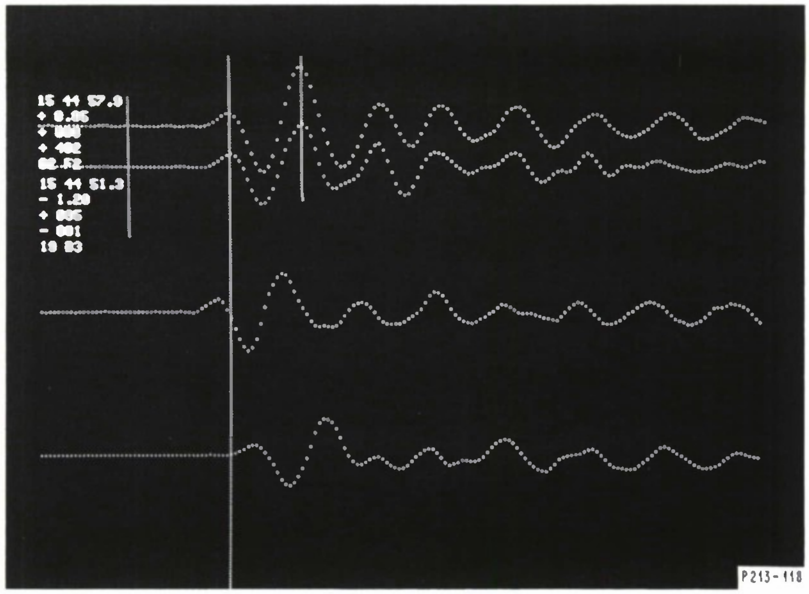


Fig. 5(b). First maximum of site B3 is aligned with same reference. Gain has been increased to show resolution that is possible.

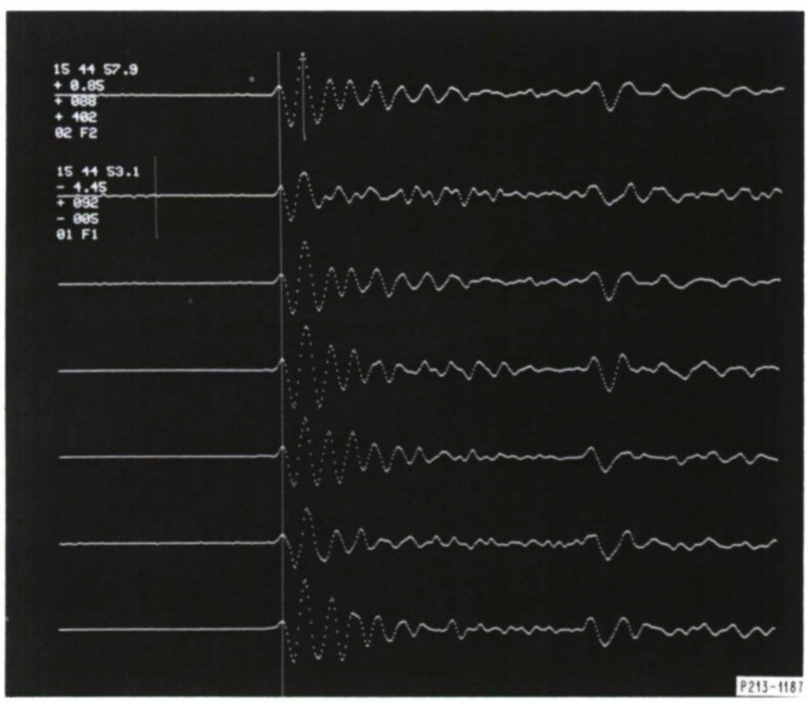


Fig. 6. All channels aligned by computer according to their time picks.

C. Display Reference (>REF)

This program will display the entire reference buffer on the screen at one time (Fig. 7). The 3840 samples will be divided into $7\frac{1}{2}$ lines of 512 samples each. A single cursor may be moved across the reference; the amplitude and GMT corresponding to the current cursor position will be displayed.

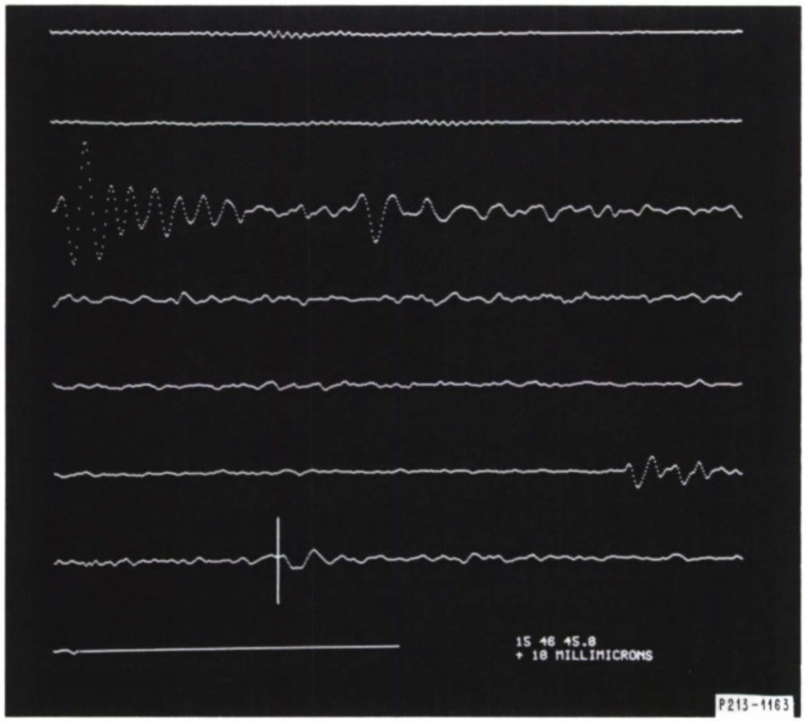


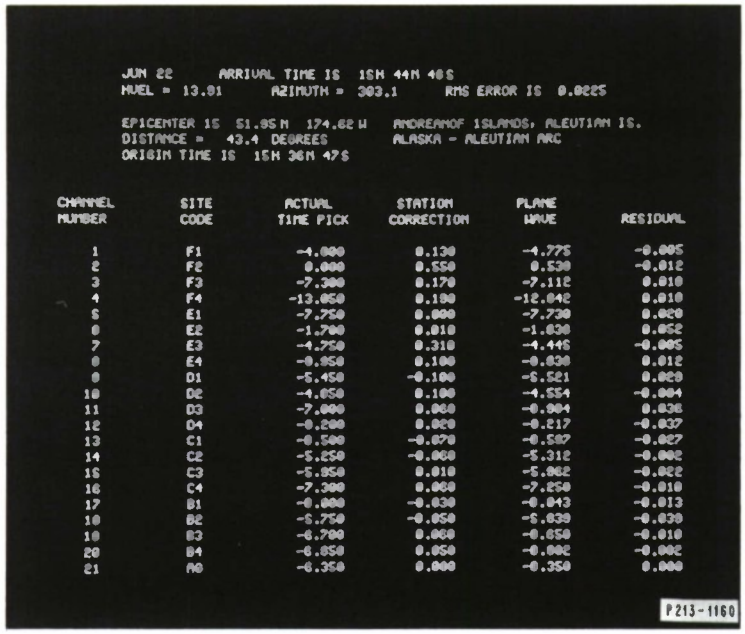
Fig. 7. Display of entire reference buffer. P-wave starts at beginning of line 3; 11 sec later, on same line, is pP (indicating that earthquake is about 40 km deep). Near end of sixth line, 98 sec after P-wave, is PcP and at cursor, 12.5 sec after PcP, is pPcP.

D. Locate (>LOC)†

This program uses the time picks made earlier, along with the latitude and longitude of each site, to calculate the azimuth and velocity of that plane wave which gives the best fit to the time picks. (The minimum-mean-square-error criterion is used for fitting.) The computer will display (Fig. 8) the date and the arrival time (GMT). This is the time at which that portion of the plane wave corresponding to the cursor mark on the reference waveform would arrive at the center of the array. If the array is LASA (Large Aperture Seismic Array, Billings, Montana), the center is defined as site A0. Otherwise, the center is the center of mass of the stations picked.

The horizontal phase velocity (kilometers/second) and the azimuth (degrees) of the best-fitting plane wave will be displayed on the next line. If the data are short-period data from LASA, station corrections will be added to the time picks and a new plane wave will be computed to fit these corrected times.

† This program is applicable only to seismic data. It is included for the benefit of the seismologist who might wish to use the Console.



JUN 22 ARRIVAL TIME IS 15H 44M 40S
MVEL = 13.91 AZIMUTH = 303.1 RMS ERROR IS 0.0225

EPICENTER IS 51.95N 174.62W ANDREANOF ISLANDS, ALEUTIAN IS.
DISTANCE = 43.4 DEGREES ALASKA - ALEUTIAN ARC
ORIGIN TIME IS 15H 36M 47S

CHANNEL NUMBER	SITE CODE	ACTUAL TIME PICK	STATION CORRECTION	PLANE WAVE	RESIDUAL
1	F1	-4.900	0.130	-4.775	-0.005
2	F2	0.000	0.550	0.538	-0.012
3	F3	-7.300	0.170	-7.112	0.018
4	F4	-13.050	0.190	-12.842	0.018
5	E1	-7.750	0.000	-7.730	0.020
6	E2	-1.700	0.010	-1.638	0.052
7	E3	-4.750	0.310	-4.445	-0.005
8	E4	-8.950	0.100	-8.838	0.012
9	D1	-5.450	-0.100	-5.521	0.029
10	D2	-4.650	0.100	-4.554	-0.004
11	D3	-7.000	0.060	-6.904	0.036
12	D4	-8.200	0.020	-8.217	-0.037
13	C1	-8.500	-0.070	-8.597	-0.027
14	C2	-5.250	-0.060	-5.312	-0.002
15	C3	-5.850	0.010	-5.862	-0.022
16	C4	-7.300	0.060	-7.250	-0.010
17	B1	-8.000	-0.030	-8.043	-0.013
18	B2	-5.750	-0.050	-5.839	-0.039
19	B3	-6.700	0.060	-6.650	-0.010
20	B4	-6.850	0.050	-6.802	-0.002
21	A0	-6.350	0.000	-6.350	0.000

P213-1160

Fig. 8. Results of locate program using time picks made in Figs. 5(a) and (b).

If the corrected horizontal phase velocity corresponds to a P-phase arrival, the location of the event (assuming a depth of 33 km) will be computed and displayed on the next few lines. This display contains the latitude and longitude of the epicenter, its distance from the center of the array, the geographic and seismic names of the epicenter region, and the origin time (the arrival time of the signal at the array minus its travel time).

Whether or not the event was located, the display will include a table of channel numbers and site codes of all channels picked, the theoretical arrival times (i.e., when the best-fitting plane wave arrives at the site), the time picks, the station corrections, and the residuals from these arrival times – i.e., the corrected observed arrival time minus the theoretical arrival time.

The program has the options of getting the above information on the teletype or the electrostatic printer, returning to the display program, or deleting one or more time picks and repeating the calculations. A repeat would be justified if some of the channels had large residuals, implying that the arrival times were incorrectly picked earlier.

The event latitude and longitude and its distance from the center of the array are stored in the Data Analysis Console common area.

E. Beamforming from Time Picks (>BEM)

The beam is the sum of all the traces which have time picks, aligned according to these time picks, divided by the number of traces picked. Because the signals add up coherently while the noise adds incoherently and partially cancels, the signal-to-noise ratio will be improved. This program will calculate the beam, place it in the reference buffer, and return to the display program (Fig. 9). If there is an event visible, it will appear on the beam halfway between the first and last arrival. Two items in the common area are changed. The instrument gain of the reference beam is set equal to the average gain of the channels making up the beam, and the reference channel identifier is changed to the code for "beam."

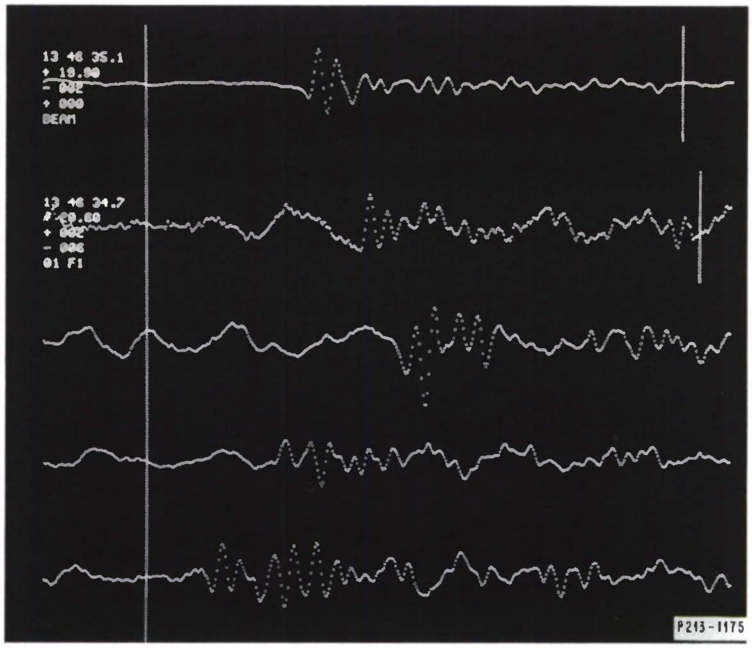


Fig. 9. These data are an event from Mariana Islands that is much weaker than previous example. Time picks have been made as shown in Figs. 5(a) and (b) and beamforming program has been called. Resulting beam is in reference position. Note improved signal-to-noise ratio.

F. Filtering (>FTR)

This program will do low-, high-, or band-pass filtering on all 3840 samples of the reference. The half-power cutoff frequencies are specified by the operator. The filters are linear recursive using bilinear transformations of the basic 3-pole Butterworth function:

$$H(S) = \frac{k}{S^3 + 2S^2 + 2S + 1} \quad .$$

After the filtering has been completed, the display program is automatically called (Fig. 10). The waveform in the reference position is the filtered version of the waveform which appeared there before the filtering program was called; thus, the same data can be repeatedly filtered by the same or other filters ad infinitum.

G. Transform and Correlate (>TAC)

This program displays 512 samples of the reference (Fig. 11). Two cursors whose positions are controlled by the knobs are used to select a portion of this reference; the parts of the reference outside the cursors are set to zero. On command, this program will compute and display the autocorrelation function of the truncated reference.

Similarly, two cursors controlled by another knob are symmetrically placed about the center of the autocorrelation function to provide an adjustable rectangular window.

The periodogram of either the truncated reference or its autocorrelation function inside the window can be computed, normalized, and displayed as power in decibels vs frequency [see Figs. 12(a) through (c)]. The periodogram is calculated from the finite Fourier transform of all 512 samples of the truncated reference. The periodogram of the windowed autocorrelation

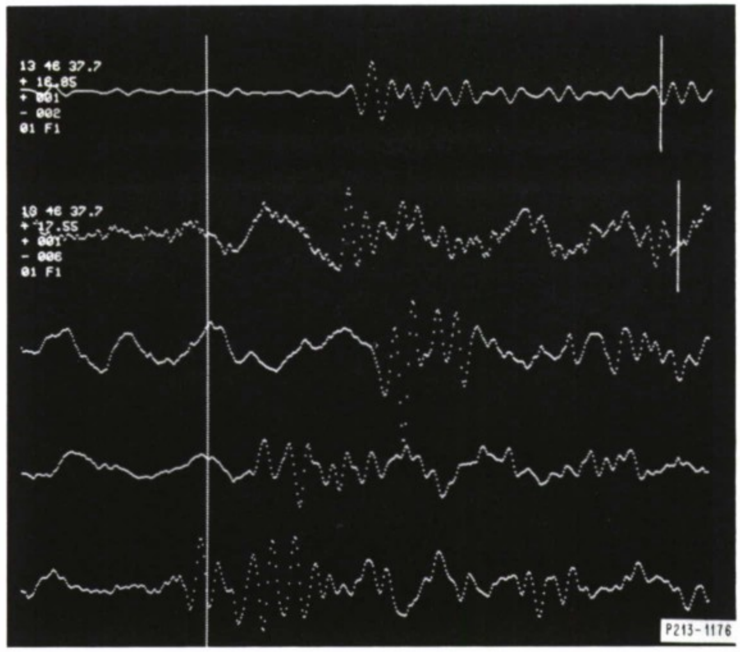


Fig. 10. Reference trace (top line) is filtered version of site F1 (second line). Operator specified a bandpass Butterworth filter with cutoff frequencies of 0.8 and 1.5 Hz. Notice that both low-frequency microseismic noise and high-frequency local noise have been attenuated.

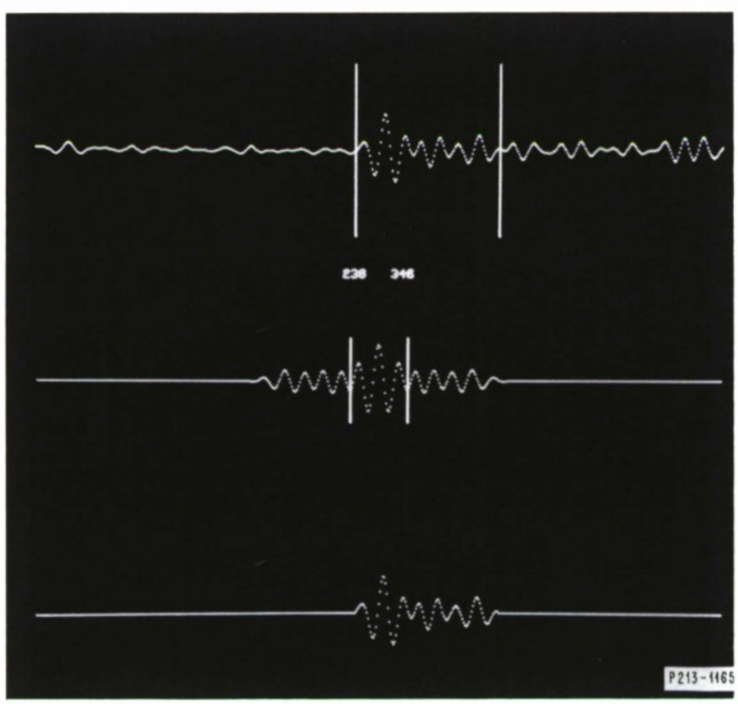


Fig. 11. Top trace is filtered reference from Fig. 10. Two cursors can be set on top trace with knobs (two numbers under cursors are their x-coordinates) to select portion of data to be processed, which is shown on bottom line. Middle trace is autocorrelation function of bottom trace.

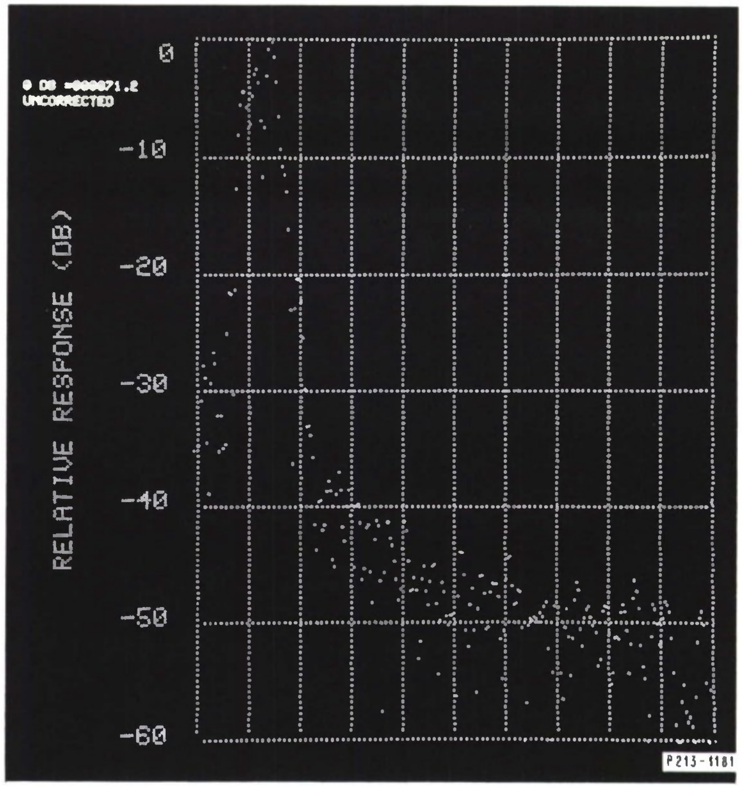


Fig. 12(o). Periodogrom of bottom troce of Fig. 11. Horizontol scole is 1 Hz per division. Here, one con see effect of bondpass filter that doto were passed through in Fig. 10.

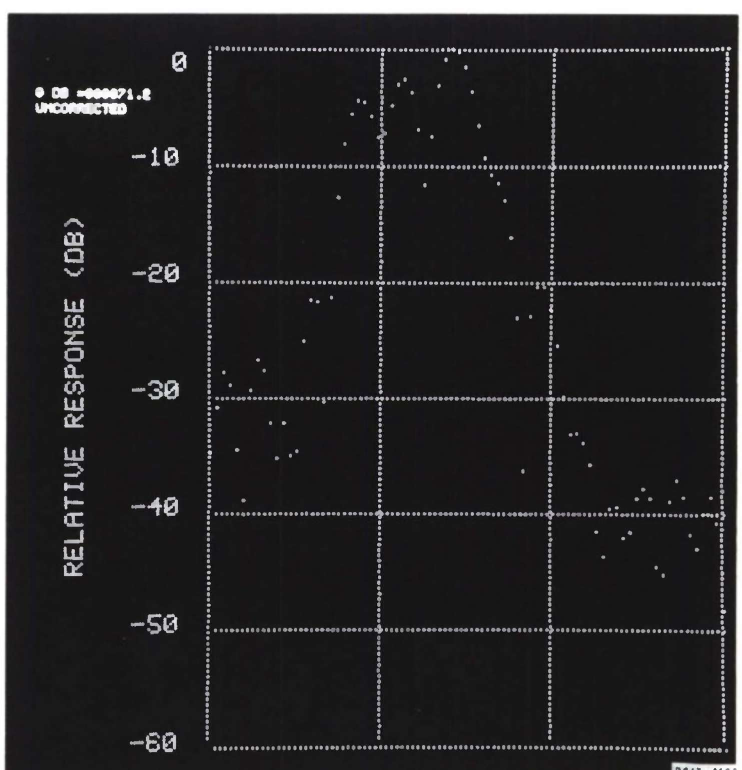


Fig. 12(b). Some os Fig. 12(a) showing first three Hertz expanded.

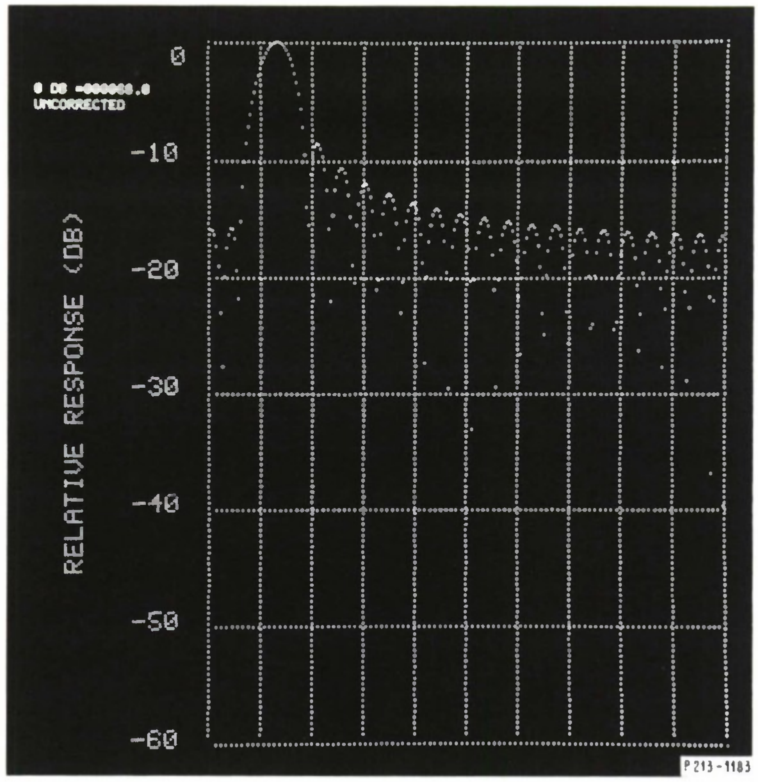


Fig. 12(c). Periodogram of portion of autocorrelation function inside vertical lines (middle trace of Fig. 11). This is smoothed version of transform of original selected data [Fig. 12(a)].

function is a smoothed version of the periodogram of the truncated reference. The narrower the window is set, the greater the smoothing will be. If the window is set to enclose all nonzero values of the autocorrelation function, the two periodograms will be identical. The entire periodogram is also saved in the common area.

H. Sonogram (>SON)

The sonogram program produces a display of signal intensity (represented by different levels of brightness) as a function of frequency (vertically) and time (horizontally) for 3200 samples of the reference trace [Fig. 13(a)]. For data sampled at 1 Hz, the frequency scale goes from 5* to 250* mHz and the time scale goes from 0 to $53\frac{1}{3}$* min.† The intensity level may be varied by a knob setting.

The sonogram is produced by passing the data through a bank of 50 constant bandwidth filters, each with a $(\sin x/x)$-type frequency response, and whose impulse response is exactly 200* sec in duration. The filters are spaced 5* mHz apart, so that they completely cover the entire frequency range. Each filter output is full-wave rectified and passed through two low-pass filters

† The frequency and time numbers that are starred assume a sampling frequency of 1 Hz (the frequency commonly used for long-period seismic data). If a different sampling frequency is used, these numbers should be scaled accordingly.

in cascade. The first is an energy-summing "integrate-and-dump" filter. It sums the output of the rectifier for 20* sec, resets itself to zero, and repeats. The second filter takes these outputs (sampled just before the dump) and performs "RC"-type low-pass filtering. The 3-dB cutoff of this filter is 5.5* mHz.

An energy profile (the normalized sum of the 50 filters as a function of time) is displayed above the sonogram. It is a standard two-dimensional display.

If the light pen is used to set two vertical time lines on the sonogram, the frequency spectrum (sum of the output between the time lines of each filter as a function of filter number) will be computed for that interval. This spectrum will be displayed with the energy profile [Fig. 13(b)].

The spectral ratio[2,3] is defined for data from short-period seismometers. It is the ratio of the energy between 1.5 and 1.9 Hz to the energy between 0.4 and 0.8 Hz for the interval between the time lines. For data sampled at 20 Hz, this ratio will be computed and typed out on request.

I. Delays from Latitude and Longitude (>DLL)†

This program will set up, for any specified channels, the time picks corresponding to an arriving plane wave from either a P or PKP phase based on a typed-in latitude and longitude. If the data are short-period data from LASA, station corrections will be included. This program will return to the display program where the user may align the traces according to these delays or form a beam to look for very weak signals.

J. Delays from Azimuth and Velocity (>DAV)†

This program will set up, for any specified channels, time picks based on an input signal azimuth and horizontal component of the velocity of a body phase or the true velocity of a surface wave. Station corrections will be included where applicable [Figs. 14, 16(a), and 16(b)].

K. Cross Correlation with Data or Chirp Filter (>CMF)

This program will cross-correlate the reference trace with a section of data or with a specified chirp filter. A chirp filter is a sinusoid with a linear frequency modulation especially designed to enhance the signal-to-noise ratio of linearly dispersive waves, such as long-period Rayleigh surface waves[4] [Figs. 15 and 16(c)]. Four filter parameters can be input to the program via the teletypewriter: the starting and ending periods, the length of the filter, and the starting phase of the sinusoid.

L. Glitch Fixer (>FIX)

This program will adjust a discontinuous data point in a specified set of channels to a more reasonable value. Using the display program, the operator sets one of the small cursors to mark the erroneous point. He then calls this program which will ask him which channels should be corrected and which method of correction should be used: "set to previous value," "set to next value," "set to zero," or "use linear interpolation." The data point is corrected in both the display and the drum data buffer.

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† These programs are applicable only to seismic data. They are included for the benefit of the seismologist who might wish to use the Console.

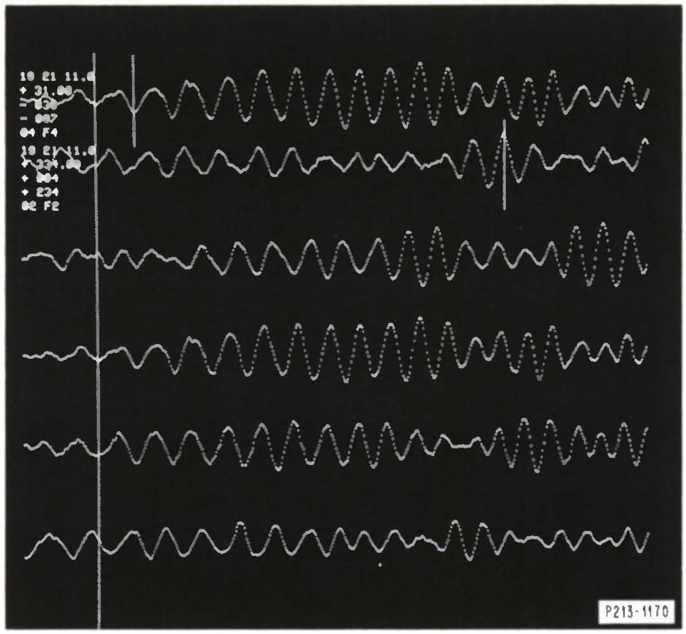


Fig. 13(a). These data are a set of surface Rayleigh waves from earthquake in Turkey. These waves have energy spread around 0.05 Hz and are sampled once per second. Due to different sampling rate, horizontal range is now 8-1/2 min. across screen. It can be seen that frequency of Rayleigh waves changes with time. Earliest signal has period of about 30 sec; latest signal has period of about 18 sec.

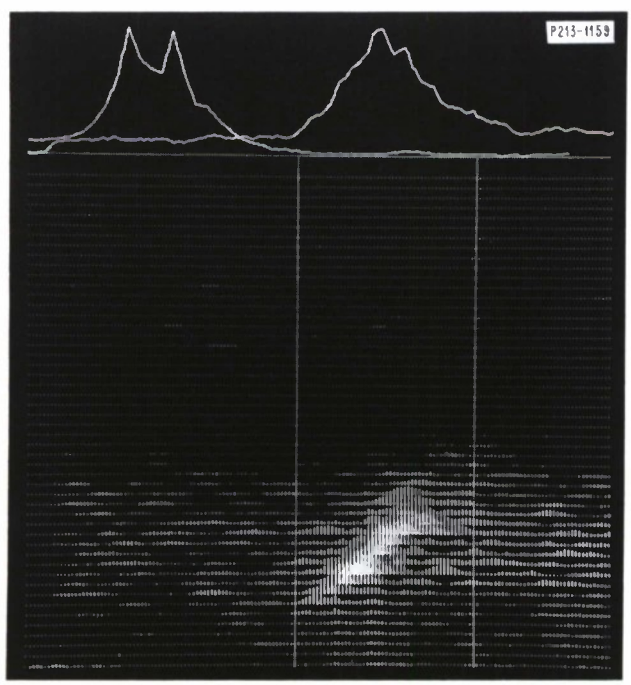


Fig. 13(b). Sonagram of reference in Fig. 13(a). In this example, time scale runs from 0 to 75 min. and frequency scale from 3.6 to 178.6 mHz. Sonagram clearly shows changing frequency of signal as function of time. Leftmost plot on top is spectrum between two vertical lines. Rightmost is energy profile. Both are normalized with linear scaling.

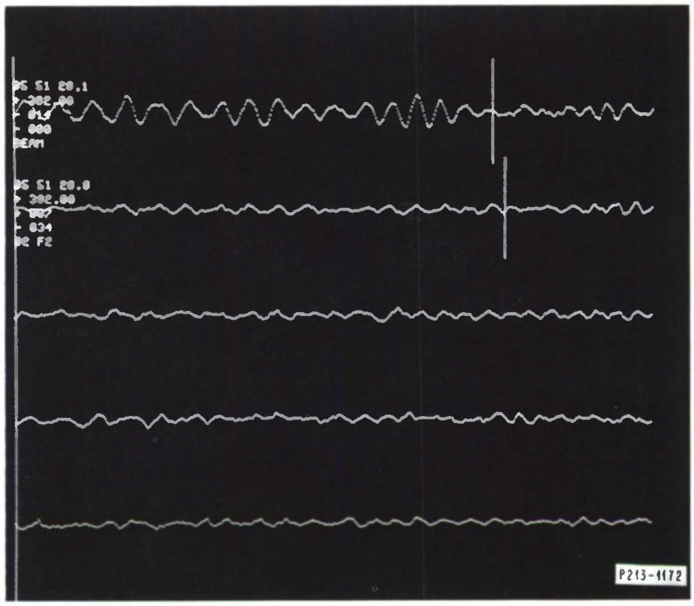


Fig. 14. Same display as Fig. 13(a), with data from much smaller event in Soviet Union. Here, we cannot see Rayleigh waves in raw data; consequently, we could not make time picks to form beam. But since approximate location of event was reported by U. S. Coast and Geodetic Survey, the Delays from Azimuth and Velocity program (>DAV) computed delays that would be associated with surface waves from that location. Beam, which appears in reference position, was formed using these computed delays. It shows signal somewhat better than raw data traces. [Data from site F2 and beam are shown in their entirety in Figs. 16(a) and (b).]

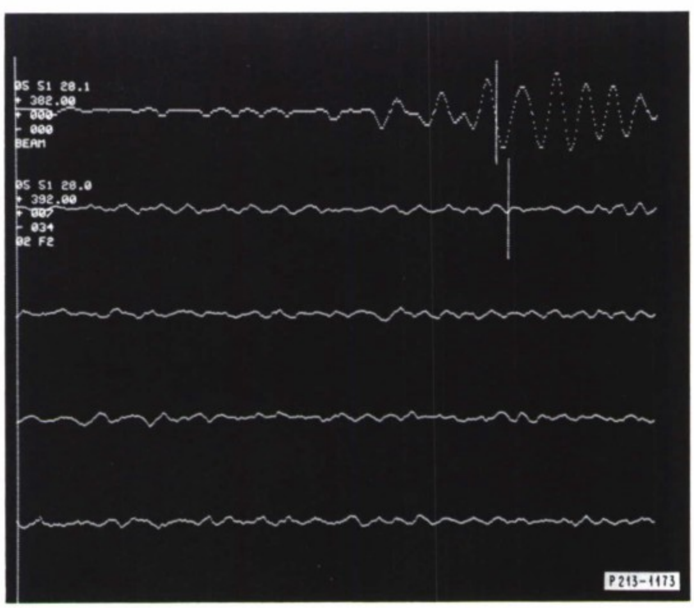
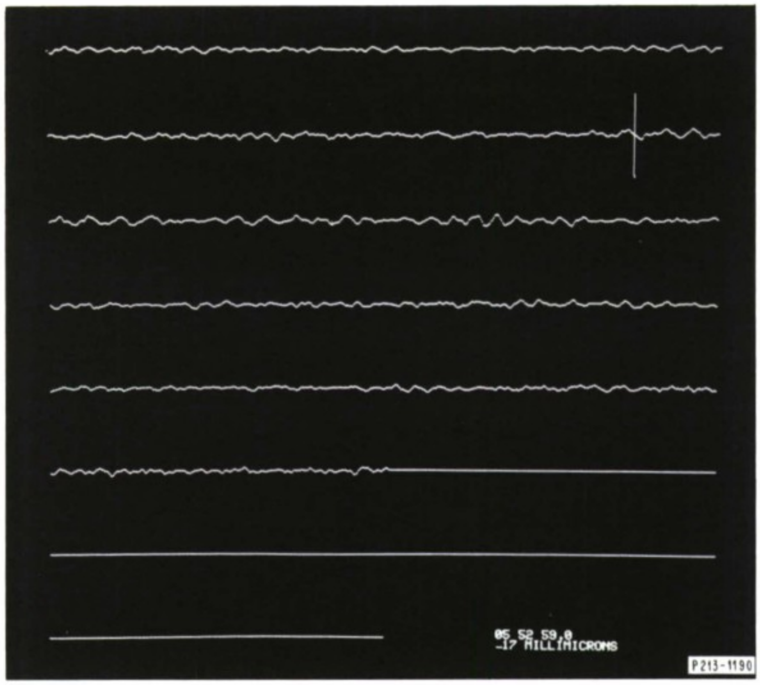
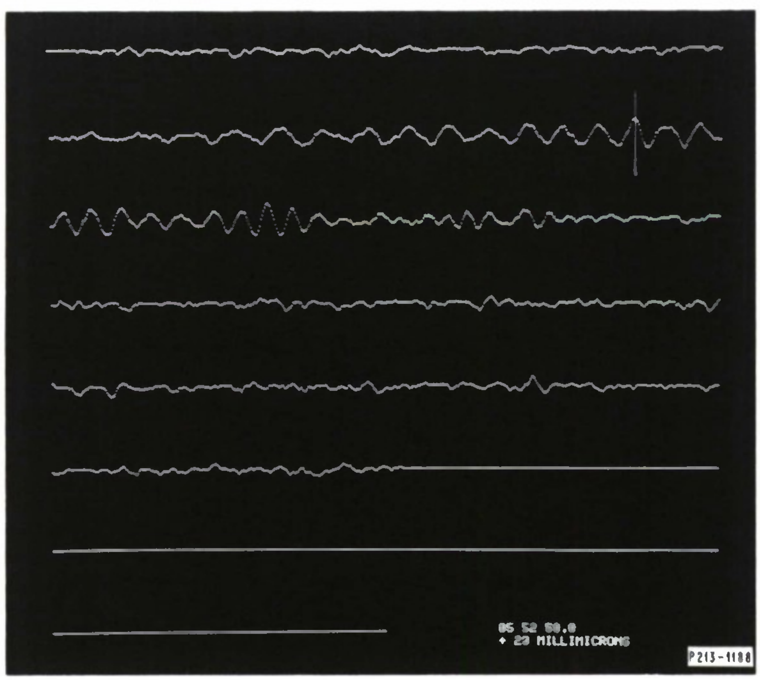


Fig. 15. Reference trace is beam shown in Fig. 14 after passing through chirp filter. Impulse response of filter was 600 sec long and went from 25 to 56 mHz. This filtering compressed dispersed energy into narrow time interval and increased signal-to-noise ratio. [Entire filtered beam is shown in Fig. 16(c).]

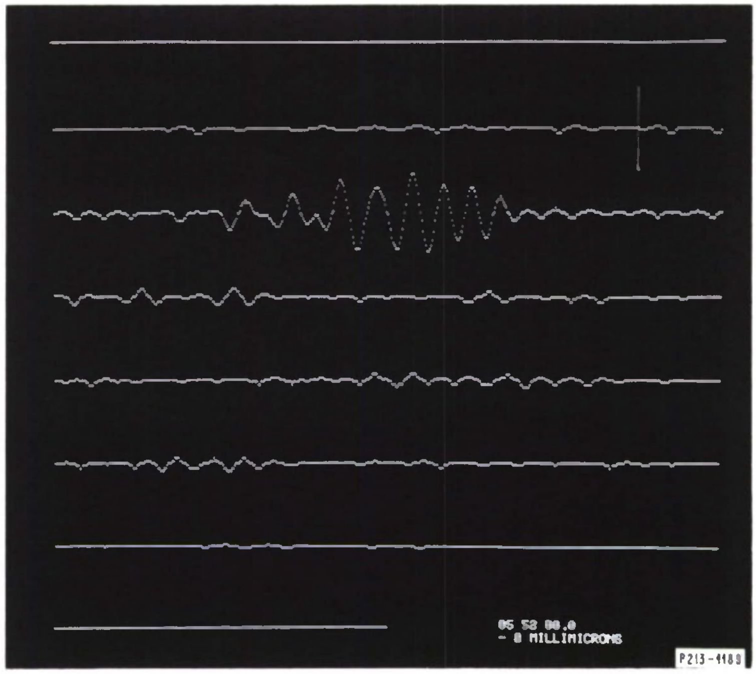


(a)



(b)

Fig. 16. One hour of data from Figs. 14 and 15 shown for comparison by using Display Reference program (Fig. 7). (a) Raw data from site F2, (b) the beam, and (c) the chirp-filtered beam.



(c)

Fig. 16. Continued.

M. Gould Output (>GLD)

This program uses a Gould electrostatic printer to produce 10- × 10-inch hard-copy replicas of the displays from all Console programs. This printer has a resolution of 1/80 inch.

N. Write a Magnetic Tape (>WTP)

This program will write all the waveform data on the drum (excluding the reference) onto any file of a magnetic tape in the format described in Appendix B.

ACKNOWLEDGMENTS

The Data Analysis Console is based on a suggestion by Mr. Howard Briscoe. Many members of Lincoln Laboratory's Seismic Discrimination Group contributed to this project by using the Console and offering constructive criticism. A few of the Console programs described in the main body of this report were written by Mr. Robert M. Sheppard and Ms. Mary F. O'Brien; the remainder were written by the authors. Appendix C was contributed by Dr. Richard T. Lacoss.

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APPENDIX A
LIST OF CONSOLE PROGRAMS

Code	Description	Operating Time	Page Number
>INT	Initializes and reads data from magnetic tape.	30 sec or more	5
>DIS	Displays the waveforms on the scope. A reference trace may be chosen and relative arrival times may be picked.	<1 sec	5
>REF	Displays the entire reference trace.	<1 sec	9
>BEM	Forms a beam and stores it in the reference trace.	10 to 30 sec	10
>DLL	Computes relative arrival times of a P-wave from a given latitude and longitude (used with >BEM).	10 sec	15
>DAV	Computes relative arrival times of a plane wave from a given azimuth and horizontal phase velocity (used with >BEM).	5 sec	15
>LOC	Calculates and displays the location of the event from the relative arrival times.	30 sec	9
>TAC	Computes and displays the autocorrelation function of the reference and the periodogram of the reference or the autocorrelation function.	5 sec	11
>SON	Computes and displays a running frequency spectrum as a function of time.	$1\frac{1}{2}$ min.	14
>FTR	Filters the reference with a specified low-, high-, or band-pass 3-pole Butterworth filter.	20 sec	11
>CMF	Filters the reference with a specified chirp filter or cross correlates the reference with selected data.	$1\frac{1}{2}$ min.	15
>FIX	Removes a glitch in the data.	5 sec	15
>GLD	Outputs any display on the Gould electrostatic printer.	20 sec	19
>WTP	Writes all waveform data onto a magnetic tape in Fastro format.	10 sec	19

The following programs were written and added to the system by the users and were not described in Sec. II of this report.

>TAP	Writes a tape in Fortran format containing up to 4 waveforms with various descriptive BCD data.	10 sec
>STP	Saves the time picks on the drum.	2 sec
>GTP	Gets the time picks from the drum.	2 sec
>SFM	Obtains beamform and spectraform power spectral estimates using up to 32 channels.	$1\frac{1}{2}$min./channel
>RST	Subtracts the reference from specified data traces.	40 sec

Code	Description	Operating Time
>RAD	Adds the reference to specified data traces.	35 sec
>IRF	Multiplies the reference by −1.	5 sec
>RRF	Reverses the reference trace about the cursor: $f(t) = f'(-t)$	5 sec
>TTT	Computes the arrival time and velocity of later phases of a signal relative to the P-wave arrival time.	10 sec
>CFP	Outputs the reference on punched paper tape.	10 sec

APPENDIX B
FASTRO MAGNETIC TAPE FORMAT

Fastro tapes are 7-track, 800-bpi, and odd parity. If the tape contains NCHAN channels sampled NF times per physical record, there are NCHANxNF+4 words in each physical record. (A word is defined to have 18 bits and occupy 3 characters on 7-track tape.) For use with the Data Analysis Console, each record must contain less than 6016 words.

The first 4 words of every record constitute the header and contain the following information.

Word 1

Ones in bits 15 and 16, zeros in bits 0-14 and 17. This identifies the tape as a Fastro tape.

Words 2 and 3

BCD coding for the time of the first sample of the record is as follows:

Word	Bits	
2	0-2	Tens of minutes
2	3-6	Units of minutes
2	7-10	Tens of seconds
2	11-14	Units of seconds
2	15-17	Tenths of seconds
3	0-1	Hundreds of days
3	2-5	Tens of days
3	6-9	Units of days
3	10	Ignored
3	11-12	Tens of hours
3	13-16	Units of hours
3	17	Ignored

By convention, January 1 is day number 1. A tape containing day number 0 will not work with the Console. The header times of successive records must be a constant increment from the previous record's header time and must correspond to the time of the first data sample in that record.

Word 4

Bits 0-6: NCHAN-1
Bits 7-17: the two's complement of NF

From the size of word 4, the number of channels is limited to 128 and the number of frames to 2048, but the product must be less than 6012.

Data are grouped in NF groups of NCHAN words on the record. Each of the NCHAN data words in a group represents a sample of data at a particular time. Thus, the third word in the fifth group is the fifth time sample of sensor 3 on that record. Each data sample occupies a full word and is a two's complement integer. NCHAN and NF must remain constant within a file of data. Fastro tapes may consist of more than one file.

APPENDIX C
LINCOLN DATA LIBRARY

Our digital tape library contains a large variety of seismic data acquired from several sites over a period of years. Currently, the greatest part of these data is several thousand hours of long- and short-period data recorded at LASA between 1965 and the present. In addition, there are data from United Kingdom short-period arrays, long- and short-period data from the Tonto Forest Seismic Observatory and from a few sensors in Norway which were recorded before NORSAR (Norwegian Seismic Array) was completed, and 1970 data from a broadband accelerometer operated by the University of California at San Diego. A very small amount of data from the completed NORSAR and ALPA (Alaskan Long Period Array) arrays is also available. However, we are currently in the process of acquiring large quantities of data recorded simultaneously at ALPA, NORSAR, and LASA, and the library should contain a sizable amount of such data by the second quarter of 1972. Data from a set of several long-period instruments installed by Lamont under Advanced Research Projects Agency (ARPA) sponsorship will also be added, but are not currently available.

Lists of data and of events are maintained and computer programs exist which use these lists to aid scientists in finding data for research. For example, a computer search could tell a scientist exactly where to find the tapes on which are recorded signals from Fiji-Tonga events at depths greater than 100 km and with $m_b > 5.0$. In addition, paper copies of these lists exist and can be accessed directly.

The digital data are supplemented by a large library of 70-mm film chips from World-Wide Standard Seismic Network stations. Most of the film chips from September 1969 to the present are on file. Selected events of interest at earlier times are also available as well as some film records from the Canadian Network stations.

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13. ABSTRACT

A software system has been developed to manipulate, process, and display digital data. This system emphasizes man-machine interaction by featuring input-output convenience, quick visual inspection of the data, and easy application of a library of processing programs. Additional programs can be added easily to the system's library. Although the facilities described herein were developed for seismology, they can be used equally well to analyze any type of digitized data.

14. KEY WORDS

seismology	digitized data	data processing
data analysis console	seismometers	Fortran
man-machine interaction	interactive graphics	